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The Application of Additive Factors Methodology to Workload Assessment in a Dynamic System Monitoring Task

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This report describes the theory that lies behind applications of Sternberg's additive factors methodology to the selective assessment of primary task workload, within the framework of a multiple resources model of human information processing. In applying this methodology, a reaction time task is performed alone and concurrently with a primary task of interest. Orthogonally, a characteristic of the RT task is varied to prolong one stage of processing. If the effect of this manipulation is greater in the presence

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of the primary task, than in its absence (i.e., an interaction), then the resource demands of the primary task are assumed to overlap with those imposed by the RT manipulation. If there is no interaction (additivity), then different resources are required. Conclusions of previous research efforts that have employed additive factors in dual task paradigms are summarized. A validation experiment is then reported in which a failure detection/monitoring task is employed as a primary task. Manipulations of perceptual and response load of a secondary reaction time task are performed, while subjects engage in a primary task of monitoring for, and detecting failures of an autopilot-controlled dynamic system. This primary task is assumed to place heavy demands on the earlier stages of processing. Convergent with the additive factors model, the presence or absence of this task is found to interact with the manipulation of display load. That is, the increase in RT due to imposing a degrading mask on the RT stimulus is greater in the presence of the failure detection task than in its absence. The presence of the primary task, however, is additive with the manipulation of response load. That is, the increase in RT resulting from a more complex response requirement is the same under single and dual task conditions. The results therefore substantiate previous conclusions that resources are separated by stages of information processing, and also validate the two Sternberg manipulations as ones that selectively probe the stage-defined resources.

A

INTRODUCTION

In a recent series of investigations, Wickens & Kessel (1979, 1980, 1981; Kessel & Wickens, 1978), have investigated the cognitive processes that underly monitoring and detection of failures of dynamic systems. One important conclusion drawn in these investigations is that when other factors are held roughly equivalent, the human operator is a better detector of system failures when he is an active participant in the manual control loop (MA mode) than when he is a passive monitor of an autopilot controlled system (AU mode). (See also Young, 1969, for a similar conclusion).

This difference notwithstanding, there remain two important reasons why system automation continues to proliferate: (a) in many systems, the system dynamics are simply too complex, by virtue of long time constants, inherent instabilities, or cascaded time integrations, for the human operator to achieve stable control. Therefore some degree of "inner loop" automation is not only desirable, but essential. (b) It commonly assumed that automating functions, once relegated to human control, will reduce human operator workload, thereby freeing processing resources to deal more effectively with other aspects of system requirements. We have argued however, that such a view may not be always correct. More specifically Wickens and Kessel (1980) showed that AU mode automation does not necessarily reduce workload from MA control, but may only shift its resource demands from response load to impose a greater load on perceptual/cognitive processes.

This conclusion is founded in the general conception that workload, and therefore the processing resources whose demand underlies the workload concept, is not unidimensional, but is instead a vector quantity (Navon & Gopher, 1979; Kantowitz & Knight, 1976; Wickens, 1979). The human procesing system draws upon a number of separate capacities or processing resource "reservoirs." The workload of a task must be defined, not only in terms of

the overall demand for resources, but also in terms of the demand level of the different resources underlying task performance. The implications of this view concern not only the way in which task workload is defined, but also the ability to predict how easily two tasks can be integrated by the human operator in a complex task scenario. Two tasks that draw upon functionally separate resources may be efficiently time-shared, while two for which there is considerable overlap, even though both may be relatively "easy," will show considerable interference.

In order to be of use to the system designer, it is necessary to specify a relatively simple taxonomy of the identity of the resource pools, so that tasks can be readily categorized in terms of their <u>demand composition</u>, that is, the quantitative demand imposed upon the different resources. Research in our laboratories, and a review of previous dual task research, has suggested that the composition of resource reservoirs may be defined by the orthogonal combination of three dimensions, each having two levels. These are (1) stages of information processing (perceptual/cognitive versus response); (2) codes of processing (spatial versus verbal, a distinction that on the output side translates to manual versus vocal), and (3) modalities of processing (visual versus auditory), nested within encoding (see Figure 1). Within this six reservoir framework, Figure 1, to the extent that two tasks share overlapping resources, task interference will be greater, and changes in the difficulty of one task will be more likely to derogate performance of the other. It should be noted that the multiple resource conception as described above, does not obviate the possibility that there may, in addition, exist a "general" resource, equally available to all more specific cells of the matrix. This issue is considered in more detail in Wickens (1981).

A goal of our current program of research with the Office of Naval

Research is to establish a methodology for conveniently and systematically identifying the locus of task demands within the framework of Figure 1. One possible approach is suggested by combining the logic and methodology of the additive factors techniques applied to the Sternberg memory search paradigm, with dual task methodology. As outlined below, this combination of paradigms has been employed with some success in previous research (e.g., Briggs, Peters, & Fisher, 1971; Logan, 1978, Spicuzza & McDonnel, 1974).

Sternberg's Additive Factors Methodology

Theoretical overview. The additive factors method derived from a paradigm, developed by Sternberg to investigate the scanning of human short term memory to determine if a stimulus probe is, or is not, contained in a memorized set of stimuli. The data from Sternberg's (1966) character comparison task provides evidence that this scanning is both serial and exhaustive. The results indicate a strong linear relationship between the number of items in short term memory and response latency suggesting the presence of a comparison process between test stimulus onset and response execution. Each additional item in memory adds approximately 38ms to the response latency. The essentially equivalent slopes for positive and negative responses also implies an exhaustive search process in that every item in memory is scanned regardless if a match was made previously.

More generally, Sternberg's approach assumes that the reaction time interval is filled with a sequence of independent stages of processing. Total reaction time, then, is simply the sum of the individual stage durations. When an experimental manipulation (factor) affects reaction time for a particular information processing task, it changes the duration of one or more of the constituent stages of processing. If two experimental manipulations affect two different stages, they will produce additive

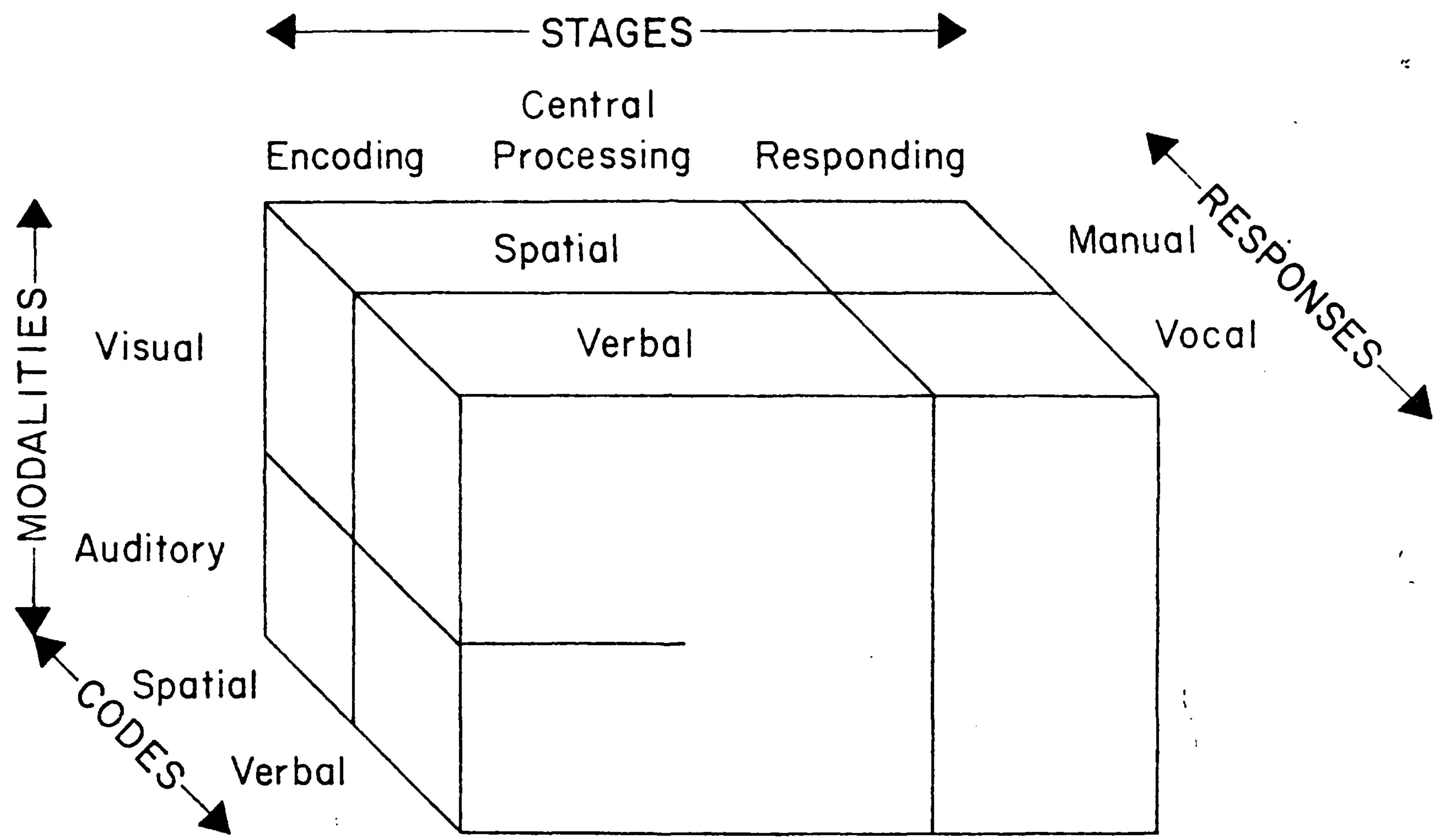

FIGURE 1. A proposed representation of the structure of processing resources.

effects on total reaction time. That is, the effect of one manipulation will be the same at all levels of the other manipulated variable (see Figure 2). However, if two experimental factors interact, so that the effect of one factor is dependent on the level of the other, they must affect some stage in common.

Sternberg (1969) utilized his character comparison task embedded in a series of multifactor experiments to investigate the effects of stimulus quality, memory set size, response type and frequency of response type on reaction time. The data revealed a converging pattern of evidence which suggests that four stages of information processing were involved in the task: an encoding stage, a comparison stage, a response choice stage, and a response execution stage. It is important to note that the additive factors method does not provide a description of the stages or the sequence in which they occur. These labels result from corroborating evidence from other sources which also support a particular stage description or sequence.

The implication that these separate stages of processing draw from partially independent processing resources has been supported by dual task research. Several experiments have demonstrated that tasks which are perceptually loaded can be successfully timeshared with tasks that are primarily response loaded (Trumbo, Noble, & Swink, 1967; Wickens & Kessel, 1980; Wickens, 1976). Although the functional separation between perceptual and central processing resources may not be as clearly defined (Shulman & Greenberg, 1971).

Application of Additive Factors to Dual Task Research. The additive factors logic has been utilized in a variety of experimental paradigms to further explore human information processing abilities. Sternberg's methodology has been employed in several dual task paradigms which have investigated the reaction time data associated with the study of the

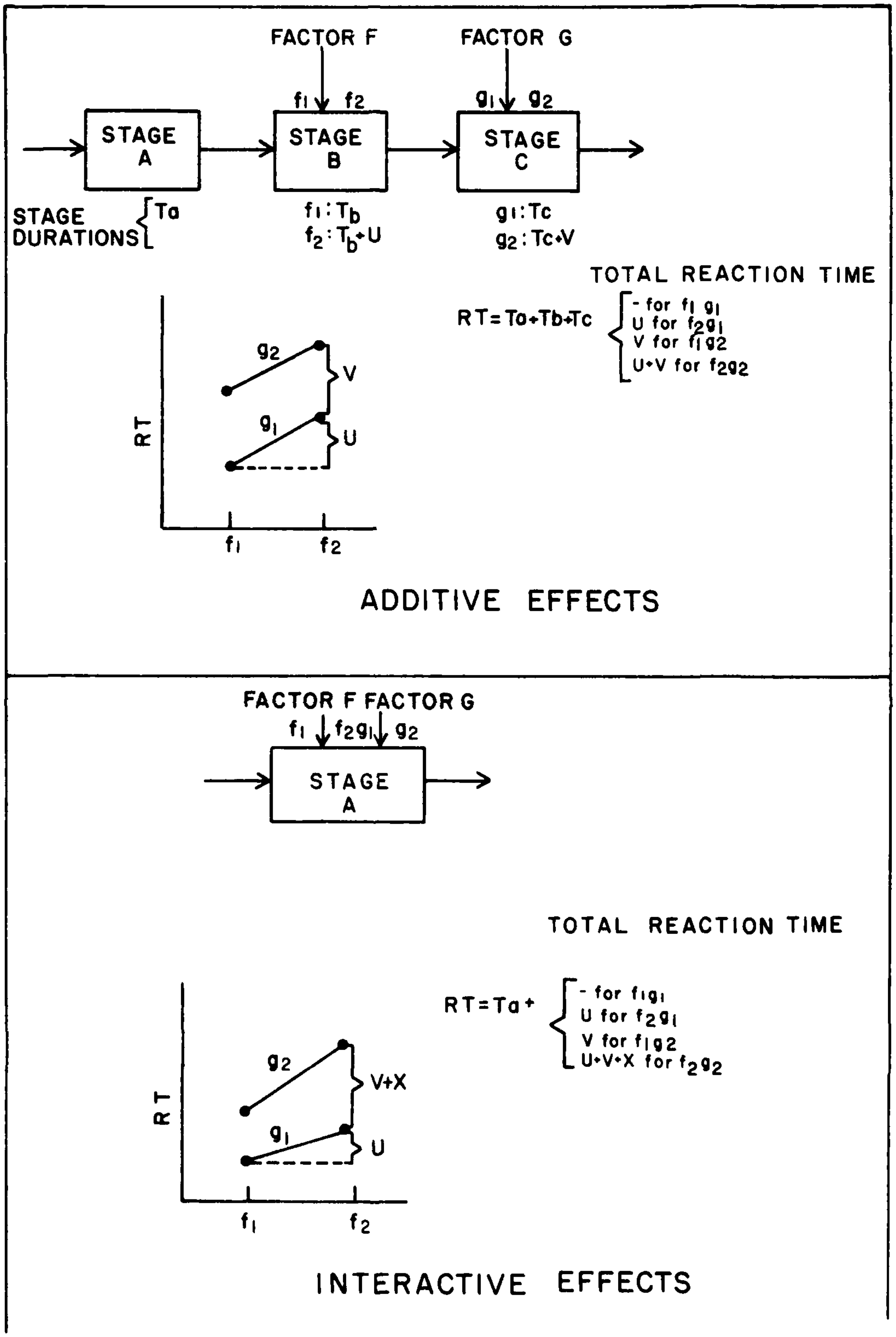

FIGURE 2. Sternberg's additive factors logic.

response decoding process (Briggs & Swanson, 1970), the localization of the divided attention effect (Briggs, Peters, & Fisher, 1972), and the processing automaticity involved in search tasks (Logan, 1978), to name a few. These applications of the additive factors method are particularly useful within the context of workload assessment since the dual task data can provide an index of processing resource overlap between the manipulated reaction time task (inferred stage of processing) and the concurrent task (Wickens, 1980).

The logic behind the use of the Sternberg task in dual task methodology is as follows: (a) a set of "Sternberg" variables have been verified to prolong identifiable stages of processing (e.g., the presence of a display mask will prolong encoding). (b) When the Sternberg task is performed concurrently with a primary task, resources diverted to and consumed by the primary task may be shared by some or all of the resources underlying the stage-related processing of the Sternberg task. This diversion will also prolong RT. (Note that in the Sternberg task, two sequential stages may consume resources from a single reservoir [Wickens & Kessel, 1980]). (c) The specific identity of the stage or stages prolonged by diversion of resources to the primary task is revealed by an <u>interaction</u> between a Sternberg variable affecting that stage, and the presence or absence of the primary task. Thus the effect of a stimulus mask might be expected to <u>interact</u> positively with the presence or absence of a perceptual primary task (e.g., signal detection): the mask effect will be greater when the primary task is present than when it is absent.

Similar logic extends to the locus of effect of a manipulation of primary task difficulty. Increasing the demand of a primary task is presumed to prolong Sternberg RT. So also will a manipulation of Sternberg difficulty. If the Sternberg manipulation and the primary task manipulation

both consume resources from a common reservoir, their effects will <u>interact</u>: the increase in reaction time of both manipulations together will be greater than the sum of the independent increases. Stated in other terms, the difficult version of the primary task enhances or amplifies the effect of the Sternberg manipulation.

In both cases (the presence or absence of a primary task, and an increase in its difficulty), if the Sternberg manipulation demands non-overlapping resources from the primary task manipulation, additivity should result. That is, the effect of the Sternberg manipulation should be no greater in the presence of the primary task than in its absence, or during the difficult level than the easy. In the example described above, we might expect the mask effect on RT to be the same in the presence of a heavy response task with minimal perceptual requirements, as in its absence.

There exists a third possible relation between the two variables of Sternberg difficulty and primary task load (either its addition or its difficulty). This is <u>underadditivity</u>, a negative interaction such that RT is prolonged <u>less</u> by the Sternberg manipulation under high load than low load conditions. The interpretation of underadditivity of task loading with a Sternberg variable is less clear. In our assumptions below, we consider it as equivalent to an additive relation. That is a clear indication that resource demands of the primary task do not overlap with the processing stage of the Sternberg task.

While the applications discussed so far have employed a Sternberg manipulation to vary a quantitative demand on a stage of processing, these may be used as well to vary qualitatively the specific structures employed in Sternberg task processing. If that structure is one of fundamental importance to performance of the primary task, a change in reaction time should also be observed (shorter RT with non-overlapping structures). Thus,

for example, the importance of encoding in performing a visual primary task should be revealed by changing the modality of the Sternberg task from visual to auditory. If a large decrease in RT results, then visual encoding aspects must be critical to primary task performance (with the implication that concurrent visual tasks should be minimized when the task is integrated with others in an operational context).

It should be noted that the Sternberg task need not necessarily be employed in making references concerning stage demands. Any reaction time task, in which the variables may be manipulated and inferred through additive factors logic to influence specific processing stages can be candidates for the particular methodology described. Finally, as employed in some of the investigations described below, RT task demands have been manipulated only at the "central processing" stage (i.e., the memory set size variable for the Sternberg task (M), or the number of possible S-R pairs in the conventional choice reaction time task (N)). Interactions of dual task conditions with this factor are assumed to reflect central processing load of the primary task. Additivity is interpreted to mean that the dual task effects are either on input (encoding) or output (response) processes. However, without a separate orthogonal manipulation of input or output load, the discrimination between these two cannot be made. Because RT data are conventionally plotted with the central processing variable (M or N) on the abscissa, the effect of these variables is often referred to as an effect on the slope, whereas input and output variables are said to influence the intercept.

Previous applications of additive factors and dual task methodology. Table 1 presents a summary of the applications of additive factors research to dual task interference. Studies may be separately categorized by whether the RT task was conventional choice RT or the Sternberg task, by whether the

Table 1

Stage of Additive Factors Manipulation

Primary Task	Encoding		M (Sternberg)		N (Choice RT) and Response Selection		Intercept	
Memory Anticipation					C_2	c_2		
		c_5	S_8	s_3^{c-}		c_5		
		c_5		s_6^{c}	C_7	s_8		
		s_8			C_9^{b}	s_8		
						s_8		
Tracking				s_1	S_1^{a}	s_1	S_3^{c}	
				s_3^{c-}			S_{10}	
				s_6^{ce}	C_4		S_{11}	
	S_1^{a}		S_{10}	s_{11}^{c-}				
Tracking Load				s_3^{c-}			S_3^{c}	
			S_{10}^{d}	s_{11}			S_9	
							S_{11}	

[1]Briggs, Peters, & Fisher, 1972
[2]Broadbent & Gregory
[3]Crawford, Pearson, & Hoffman
[4]Damos & Wickens
[5]Egeth
[6]Griffeth & Johnston
[7]Keele
[8]Logan, 1978
[9]Logan, 1979
[10]Schiflett
[11]Spicuzza & O'Donnel

Notes

a) Manipulation of speed-accuracy tradeoff.
b) Becomes additive with consistent mapping.
c) Auditory Sternberg.
d) Manipulation of display format from all spatial to mixed verbal-spatial.
e) A simple reaction time task was used as the primary task.
-) Indicates underadditivity.

primary task was one involving short term memory or tracking (practically all studies fell into one category or the other), by the locus of manipulation of the RT variable, and finally by the nature of the observed effect (additive or underadditive versus a positive interaction). In the table, the letter of each entry designates whether a Sternberg memory search or choice reaction time task was employed. Its position in each column, as well as it case, indicates whether an interaction (left, upper case) or additive (right, lower case) relation was found. The superscript codes the identity of the investigator, identified at the bottom of the table.

Examples of some of the applications will now be described. The integration of dual task methodology and additive factors methodology, either explicitly or implicitly, dates to 1965, when subjects of Broadbent and Gregory (1965) time-shared a reaction time task with a task loading short term memory. RT was measured at two levels of central processing uncertainty (number of stimulus-response alternatives) which affected single task RT. The effect of the dual task memory load, while prolonging overall RT was to reduce the influence of the central processing variable. That is, to produce an underadditive relation between the two variables. This relation suggests the increased memory load was utilizing functionally different resources from those important in selecting the RT response. In their experiment, a separate orthogonal manipulation of S-R compatibility produced a positive interaction with the memory load variable. The incompatible S-R pairing was more affected by dual task load than the compatible version, a result replicated by Keele (1967).

The results of an investigation by Damos & Wickens (1977) appears, on initial consideration, to contradict those of Broadbent & Gregory. They obtained a positive interaction between the dual task loading and the N variable of a choice RT task. However, Damos and Wickens used tracking,

rather than memory as the primary task. If the locus of the N variable is assumed to be in the response selection stage this result, coupled with Broadbent and Gregory's observation, is consistent with the conclusion that tracking loads response resources, different from the perceptual/central processing resources demanded by Broadbent and Gregory's memory condition. That is, response selection load (number of alternatives) does not interact positively with a short-term memory primary task, but does interact with a tracking primary task.

In a study by Briggs, Peters, and Fisher employing the Sternberg classification task, RT duration was systematically varied at encoding (a manipulation of speed-accuracy stress), central processing (set size, or N), and response. These manipulations were imposed with and without a tracking task. The authors observed the greatest interaction of the presence or absence of tracking with the encoding variable, and concluded the locus of the processing bottleneck with tracking to be encoding. Translating these results into a multiple resource interpretation, this suggests that the locus of tracking demands are at the earlier processing stages, a conclusion that is inconsistent with that of Damos and Wickens. Unfortunately, this conclusion appears to be based upon the authors' assumptions that the speed-accuracy tradeoff is itself a manipulation of encoding load. This conclusion may not however be adequate, as equally plausible models of the speed accuracy tradeoff suggest its locus to be at response selection (McCarthy, Kutas, & Donchin, 1978). If the latter is assumed, the results are consistent with those of the previous investigations.

More recently Logan (1978) has applied the Sternberg task to infer the locus of short term memory load. Of a host of RT variables manipulated, Logan observed that the only one to show a pattern of positive interactions with the presence or absence of the memory task, was memory set size (N).

All other variables showed the same magnitude effect in dual as in single task conditions. Included in Logan's manipulations was a qualitative change of response type (manual versus speech).

Three published results extend the dual task/additive factors paradigm to the more applied domain of the pilot's flight task. Spicuzza and O'Donnel (1974) manipulated only memory set size of a Sternberg task, with an easy and difficult maneuver in a simulated flight task. When RT was plotted as a joint function of the four levels of memory load and of conditions, the effects both of imposing the task and of increasing its complexity were additive with the set size manipulation of central processing load, showing an increase in the intercept across the three conditions. Since neither encoding nor response load were manipualted, the specific locus of this demand increase could not be identified and was categorized merely as "perceptual-motor."

In a separate experiment, an auditory version of the Sternberg task was employed, all other features being similar. While a large increase in the intercept was observed from single to dual task conditions, this was accompanied by a decrease in slope, an underadditivity that suggested some degree of overlap in processing at the high memory load conditions. The RT function in the two dual task conditions did not differ from each other.

Crawford, Pearson and Hoffman (1978) also used the Sternberg task in conjunction with two primary tasks: A simulated flight maneuver (with an easy and difficult version), and the anticipation of data entry into a multi-function keyboard (MFK). Like Spicuzza and O'Donnel, only memory set size (the slope variable) was manipulated. Their results indicated an increased intercept resulting from the MFK entry (inferred, but not validated to result from increased encoding load), a further increase in intercept for the easy, and again for the difficult versions of the flight

control task. No change in slope was found with the MFK task. However, the slope systematically decreased with imposition of the flight task, and again with the increase in flight task difficulty. While the authors attribute this effect to an increase in central processing rate with task load, as is warranted by a literal interpretation of slope as an indication of processing capacity, such a conclusion seems counterintuitive. Instead, since the decreases in slope were accompanied by large intercept increases, this underadditive trend appears more consistent with the view of an increased overlap of central processing with other processes, concommitent with the greater primary task load.

Whereas the two previous investigations were conducted in simulators, Schiflett (1980) has extended the Sternberg task to an actual airborne environment, the landing approach of an NT-33A trainer aircraft, employing a conventional heads up display, or an all spatial Klopstein display. The loading task was performed under two levels of task difficulty, induced by placing a time delay in the display loop. Schiflett observed both slope (central load) and intercept to increase, with the introduction of the flight task (i.e., from the baseline control data) and again with the increase in control difficulty, imposed by the time delay. Furthermore, the slope of the RT function was less with the Klopstein display than with the conventional display. The reduction in slope was greater at the difficult display value. These results are consistent with the assumption that display delay, and the conventional (as opposed to the Klopstein) display both impose increased central processing loads. However the effect of display type on the intercept value was inconsistent across the two subjects.

The composite results of eleven investigations (which incorporate 32 manipulations of either the primary or the Sternberg task) are summarized in

Table 1. Note that the effect of the Sternberg variable of set size (M), and the choice reaction time variable N is treated separately within the table. This is because they seem to have qualitatively different effects. Clearly N influences the complexity of response selection, while M does not, since only two responses are ever required in the Sternberg task.

Taken as a whole, there do appear to be certain systematic trends that emerge from the data of Table 1. These may be roughly summarized as follows: (1) When tracking is a primary task, its introduction seems to produce an interaction with response selection variables of a reaction time task, but an additive or underadditive relation with memory set size of the Sternberg task. Underadditivity seems to result when the Sternberg stimuli are auditory. (2) There are clearly "intercept" effects with the introduction of tracking and increases in its difficulty when a Sternberg task is employed. However, it is impossible to determine what stage of processing this intercept effect is reflecting. It can only be asserted that the stage is not memory search, since the operational definition of the intercept effect was an increase in reaction time from variables other than M. (3) When the primary task involves memory or anticiption (presumably involving heavier cognitive loads), the results suggest an interaction between primary task presence and response-selection variables of a choice reaction task, but additivity with response variables of the Sternberg task. This difference in effect is hard to explain. (4) With a memory task and the manipulation of memory set size, the results appear mixed, with additivity and interactions both reported. (5) There is too little data available to warrant conclusions concerning the effects when encoding variables are manipulated. However, again the results appear mixed.

One further relevant observation from Schiflett's data (#10) is the reduced slope observed with the fully spatial Klopstein display, compared

with the integrated verbal-spatial conventional display. This may be interpreted as reflecting the spatial-verbal disctintion of resources--an increased efficiency when the competition for verbal resources between the verbal Sternberg task and the display processing is eliminated.

Because the results reviewed were at least encouraging in suggesting that the Sternberg additive factors logic could be employed as a resource-specific index of task workload (i.e., interactions and additivity were both observed), the current investigation was intended to provide further a validation of the Sternberg task and then to apply this logic to specify in greater detail the processing resource demands in dynamic system monitoring. In their experiment, more specifically, Wickens & Kessel (1979, 1980) concluded on the basis of task interference effects that the locus of detection demands were perceptual/cognitive. The objective of the present experiment is to use this knowledge of a perceptual demanding primary task to validate that its presence will interact with a perceptual Sternberg variable, and be additive with a response variable.

A modified version of the AU failure detection task employed by Wickens and Kessel (1979, 1980), was used, in which system order changes were induced by a non-catastrophic ramp from first to second order, rather than the step change used by Wickens and Kessel. In conjunction, the Sternberg manipulations included the presence or absence of a stimulus mask (perceptual load), and the requirement to make a simple vs. complex response (response load). Following the conclusions of Klapp (1977), we assume that the more complex response will take a longer time to initiate, and therefore prolong RT. Failure detection was performed at two different levels of display complexity to determine how the selective Sternberg index of workload varied with primary task difficulty.

METHOD

Subjects

Eight right handed male undergraduate students from the University of Illinois volunteered to participate in all experimental manipulations. All subjects had normal vision and were paid $2.50 per hour plus additional bonuses. The degree of right handedness was also evaluated for each subject to insure that the right hand was clearly dominant (Bryden, 1977).

Apparatus

Subjects were seated in a booth containing a 10 cm x 8 cm Hewlett Packard 1330a cathode ray tube (CRT), a hand control joystick with an index finger trigger operated with the left hand, and a spring-return pushbutton keyboard operated with the index and middle fingers of the right hand. The viewing distance from the subject's eyes to the CRT was approximately 86 cm, subtending a visual angle of 5 degrees. A Raytheon 704 sixteen bit digital computer with 24k memory was used to generate and control a single axis pursuit tracking display, present the Sternberg stimuli, and process subject responses on both tasks.

Tasks

Failure detection. This task is similar to the automatic mode (AU) of failure detection reported in Wickens and Kessel (1979a). In the present study, subjects were required to monitor a single axis pursuit tracking display which moved horizontally across the CRT. The target path was driven by a summation of two sinusoidal inputs while the autopilot transfer function consisted of a pure gain and 200 ms time delay to specify cursor

position on the basis of the error. A random noise disturbance was added to the output of the cursor. Thus the task might simulate a system following a semi-predictable path while compensating for disturbance gusts. System failures were simulated by a ten second linear ramp change in dynamics from a first order to a second order system. Subjects were instructed to press the joystick trigger with the left hand when they thought a failure had occurred. Four, five, or six failures occurred randomly during the two minute trial. A minimum of eight seconds had to elapse after a detection or miss before another failure could occur. As a manipulation of failure detection difficulty, the cutoff frequency of the random noise function was varied as an experimental factor (.32 Hz to .5 Hz) within subjects. The computer recorded hit latency and false alarms (detection responses that did not occur within 10 seconds after the failure).

Sternberg task. The general Sternberg paradigm required subjects to recognize previously presented spatial information. Specifically, a spatially defined target, consisting of a random dot pattern, appeared for study on the display for ten seconds prior to each failure detection trial. Each presented pattern was drawn from an alphabetized set of twenty four separate and distinct dot patterns adopted from Wickens and Sandry (1980). After ten seconds, the dot pattern was removed and a clear box appeared in the center of the screen. A series of test stimuli were then presented and the subject responded either "yes", if a particular test stimulus was identical to the memorized stimulus, or "no", if the test stimulus was different from the memorized stimulus. "Yes" and "no" responses were recorded by pressing the upper and lower keys with the right middle and index fingers, respectively. The computer recorded reaction time and

errors.

In the perceptual load condition, a grid of line segments was placed over the stimulus box in order to hinder the perceptual processing of the dot patterns. The mask had been pretested to insure that no dot pattern's identity was obliterated. The mask only served to prolong the single task reaction times.

In the response load condition, subjects were required to press two buttons in succession in order to record a specific response. For a "yes" response, the subject pressed the upper key followed by the lower key. The second key was to be depressed within a time window of .3 seconds to .6 seconds following the first. The desired result was a smooth, coordinated response which produced slightly higher single task reaction times than simply a single key response. Similarly, a "no" response was recorded by first pressing the lower key and then the upper key within the .3 second window. Nonresponses were recorded by the computer when the subject was either too fast (<.3 seconds) or too slow (>.6 seconds) in pressing the second key. The reaction time interval began when the first key was depressed.

Experimental Design

A within subject design was employed in which each subject participated in all experimental manipulations. The Sternberg conditions included a baseline condition (no mask, single response), a perceptual load condition, and a response load condition. The failure detection difficulty manipulation varied the cutoff frequency of the random noise function from .32 Hz to .5 Hz. Each of these task manipulations was performed under single task conditions, and paired with all levels of the other task in dual

task conditions. All subjects participated in six sessions consisting of two days of practice and four days of data collection. Each session lasted one hour and took place on consecutive days. The cutoff frequency levels were administered on different days and the particular order was counterbalanced for each subject to avoid the bias of any particular sequence.

Procedure

The practice days were divided into single task and dual task training sessions. All subjects received enough training in the experimental conditions to insure relatively stable performance.

The four experimental days each consisted of fourteen total trials. The failure detection difficulty level remained constant throughout a particular experimental session. During each session, subjects were required to perform two single task failure detection trials, six single task Sternberg trials, and six dual task trials. These Sternberg trials were administered in four alternating blocks of three single task trials followed by three dual task trials. The three Sternberg manipulations consisted of a no- mask single-key response condition (baseline), a mask single-key response condition (perceptual load), and a no- mask double-key response condition (response load). Two replications of each Sternberg manipulation were presented to the subject for both single and dual task conditions. Each trial lasted approximately two minutes and between trials, the subject was given feedback concerning task performance and bonus earned.

Experimenter instructions designated the failure detection task as primary so that subject performance on this task in both single and dual task conditions should be essentially equivalent. Therefore, secondary Sternberg performance should reflect changes in the processing demands of

the primary task.

The bonus system reinforced these instructions. The failure detection bonus depended on hit latency and was halved if one false alarm was generated. Two false alarms resulted in elimination of the failure detection bonus altogether. The Sternberg bonus was contingent on acceptable primary task performance (dual task = single task) and was dependent upon a reduction of reation time below the previous day's single task reaction time score. Excessive errors also reduced the bonus that could be earned.

RESULTS

The summary data for both the failure detection and Sternberg tasks are presented in Table 2. In the statistical analysis performed on the data, only the main effects of interest (primary load, Sternberg condition, and dual task load), and their interaction with other variables will be reported. Single and dual task Sternberg performance for both the perceptual and response load conditions are graphically portrayed in Figure 3. Reaction time performance in the .32 Hz and .5 Hz conditions is shown in the top and bottom panels respectively. Separate repeated measures ANOVAS were performed on the left (perceptual load) and right (response load) panels. (Note that the data points for the low load conditions are the same in both cases.) The experimental results indicate that the interaction between perceptual load and the presence of the failure detection task was statistically significant, $F(2,14) = 8.10$, $p < .01$. Under dual task conditions, a significantly greater increase in Sternberg reaction times was obtained for the mask manipulation compared to the no mask condition. As suggested by the data in Figure 3, no significant positive interaction was found between response load and failure detection. When the .32 Hz and .5 Hz data were analyzed separately, an instance of underadditivity was found for the .32 Hz condition, $F(2,14) = 9.81$, $p < .01$: the double key response reaction times were not as severely disrupted under dual task demands as the perceptual load reaction times.

The ability of subjects to maintain consistent primary task performance for both single and dual task conditions is an important requirement for any interpretation of the dual task data. A comparison of the failure detection

Table 2

Mean Task Latencies (seconds)

for Each Processing Load Condition

Load	Condition: Baseline	Mask	Double Key
Failure Detection			
Single Task			
.32 Hz	5.594		
.50 Hz	5.201		
Dual Task			
.32 Hz	4.943	5.127	5.220
.50 Hz	5.119	5.094	5.064
Sternberg			
Single Task			
.32 Hz	.617	.687	.667
.50 Hz	.604	.676	.674
Dual Task			
.32 Hz	.784	.914	.794
.50 Hz	.780	.906	.821

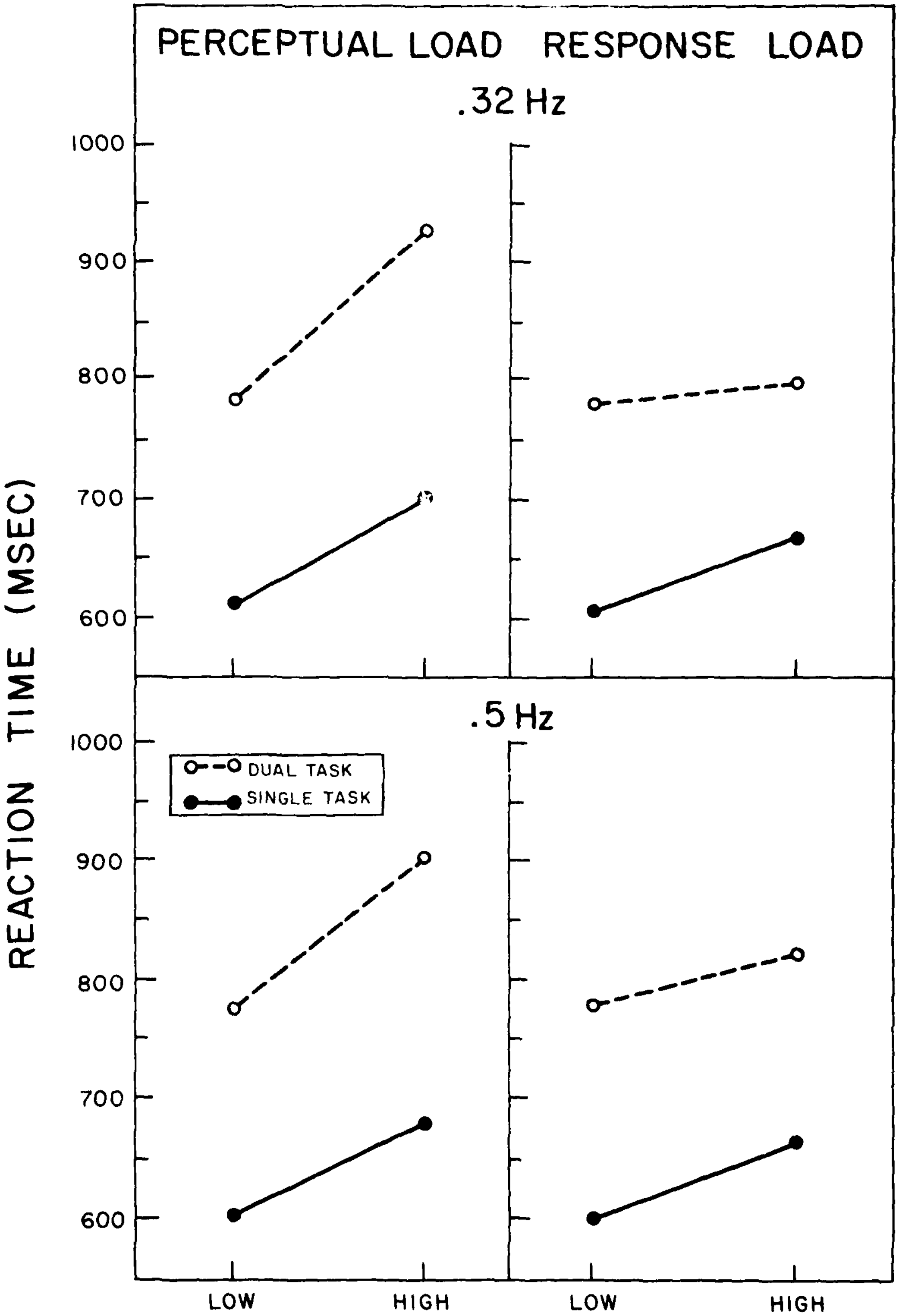

FIGURE 3. Effect of Sternberg manipulation and dual task load on reaction time. (Note that the low load condition is identical in the left and right panels.)

data across conditions (see Table 2 and Figure 4) revealed essentially equivalent performance for these two conditions, $F(3,21) = 2.17$, $p > .122$. In most cases in fact, subjects were able to maintain superior performance under dual task demands. This was particularly true in the low cutoff frequency condition (.32 Hz) and accounts for the reliable interaction between Sternberg and failure detection conditions ($F(3,21) = 3.68$, $p < .028$). Thus, we can be relatively secure in the assumption that similar amounts of processing resources for the failure detection task were used in single as well as dual task conditions. This assumption permits an interpretation of Sternberg reaction time decrements as an indication of task manipulations.

Although maintaining single task failure detection performance under dual task demands is an important requirement for any interpretation of the reaction time data, an equally important consideration is the ability of subjects to avoid utilizing a "resource tradeoff" strategy in producing the observed reaction time decrements. Large variations in dual task failure detection performance across Sternberg conditions may reflect this strategy and could potentially account for the particular pattern of Sternberg data shown in Figure 3. If the higher reaction times in the perceptual load condition are consistently linked with relatively lower failure detection latencies (compared with the response load condition) then a resource tradeoff strategy may have been utilized. Under this interpretation, processing resources are assumed to be diverted (traded off) from the Sternberg task (resulting in higher reaction times) and applied to the failure detection task (resulting in lower hit latencies). As a result, variations in reaction time performance across Sternberg conditions could be

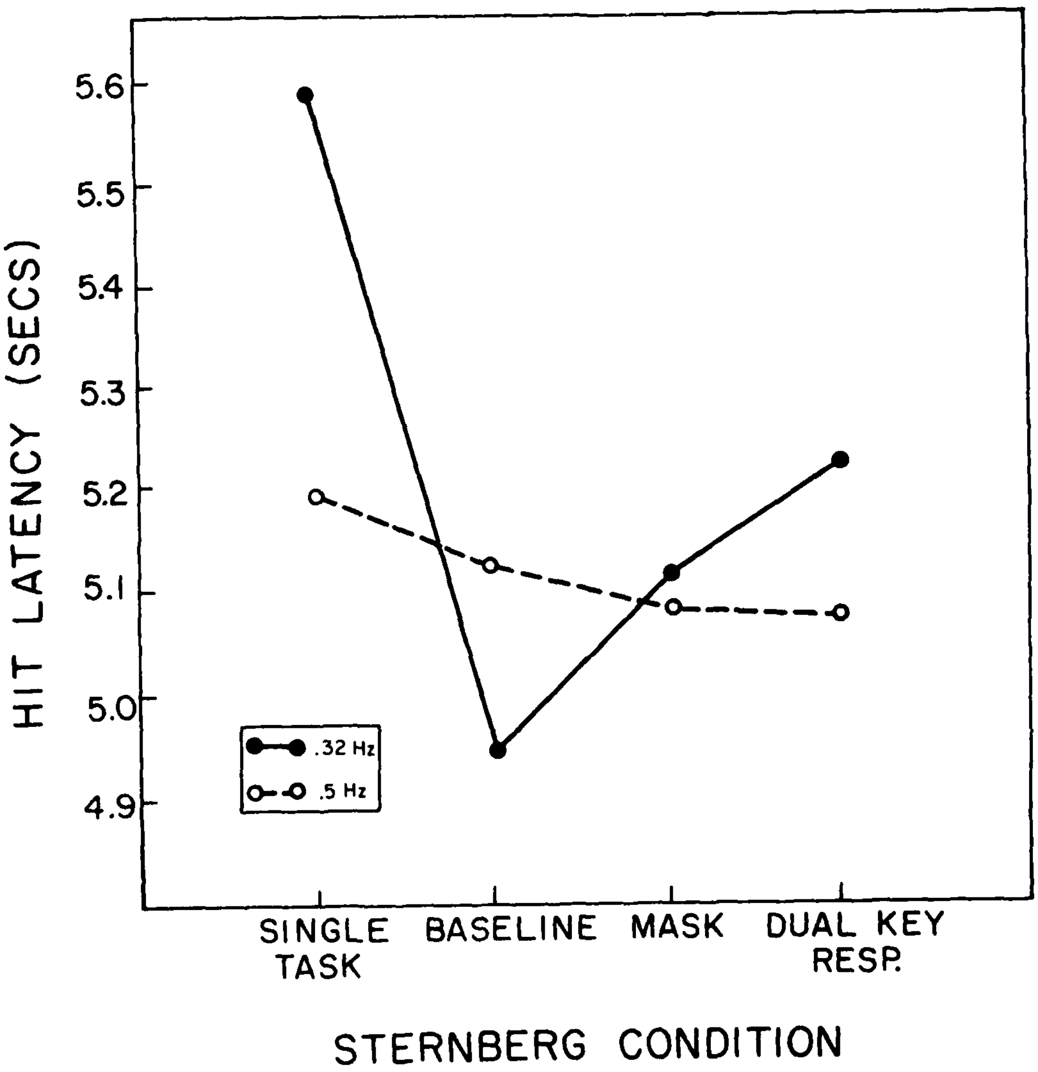

FIGURE 4. Effect of Sternberg conditions on failure detection hit latency.

explained in terms of subject strategy without reference to competition among hypothesized pools of processing resources.

The presence or absence of such a tradeoff can be illustrated through the use of a performance operating characteristic (POC) (see Figure 5). The efficiency level of the two tasks performed concurrently can be represented within the POC space. Single task performance is indicated by the point of intersection of the POC with the two axes. Dual task performance is identified as a single point within the space representing the decrement score on both tasks relative to their respective single task performance levels. Shifts along the positive diagonal toward the upper right represent improvements in time sharing efficiency. Shifts along the negative diagonal represent variations in resource allocation policy.

In order to compare tasks which utilize different dependent variables, the performance measure of each task is converted to a common dimensionless unit such as a normal deviate (Wickens, Mountford, & Schreiner, 1981 (in press)). In the present study, dual task difference scores for both the reaction time and hit latency measures were divided by a normalizing factor (the standard deviation of each measure was computed across replications for each subject. The mean of these s.d's across subjects was the normalizing factor). The normalized decrements were plotted within the POC spaced for .32 Hz and .5 Hz manipulations (in Figures 6 & 7). A comparison of these dual task difference scores along a common measuring scale reveals a clear separation in time- sharing efficiency of respective POCs for the perceptual and response load conditions. The perceptual load condition disrupted dual task efficiency to a much greater extent than in the response load condition.

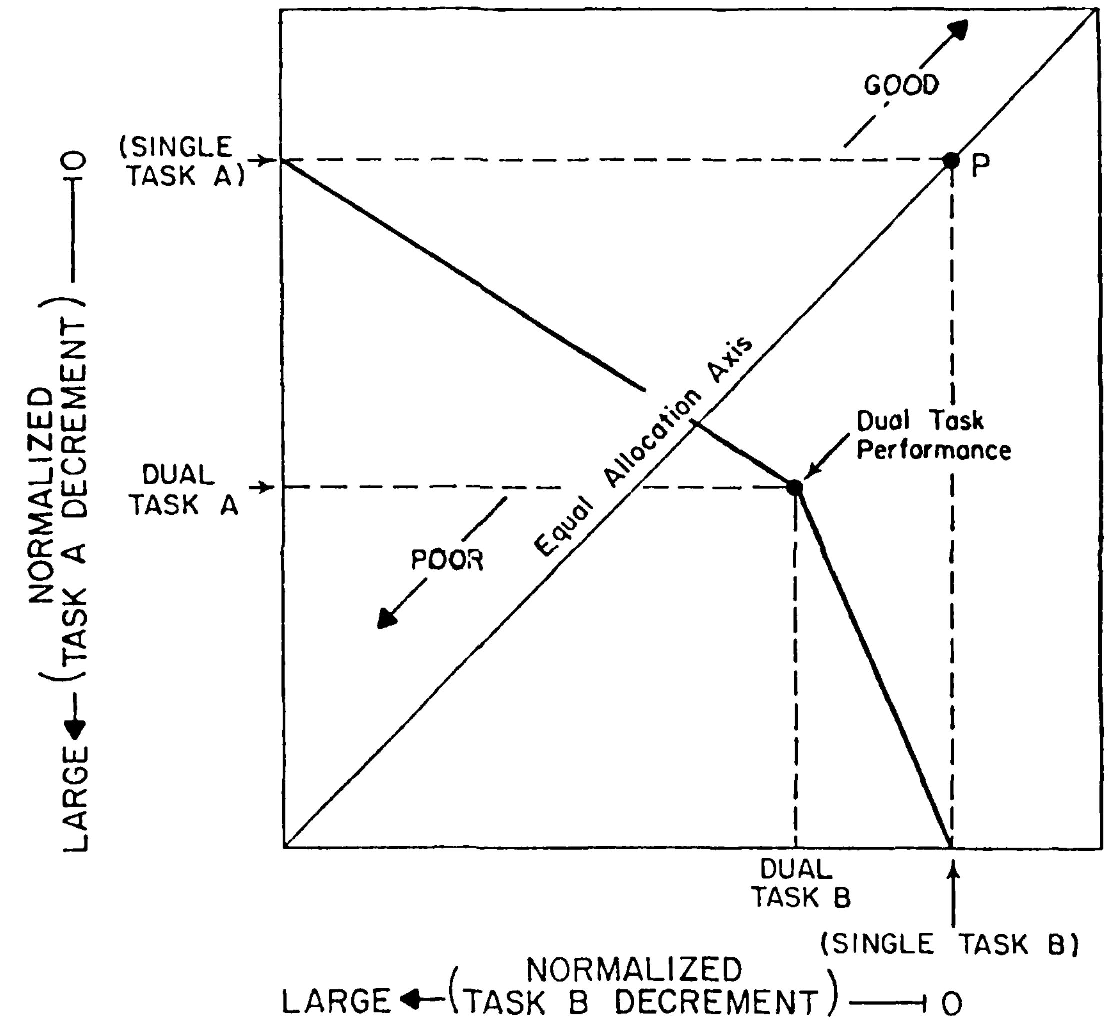

FIGURE 5. Hypothetical performance operating characteristic (POC) representation of dual task data.

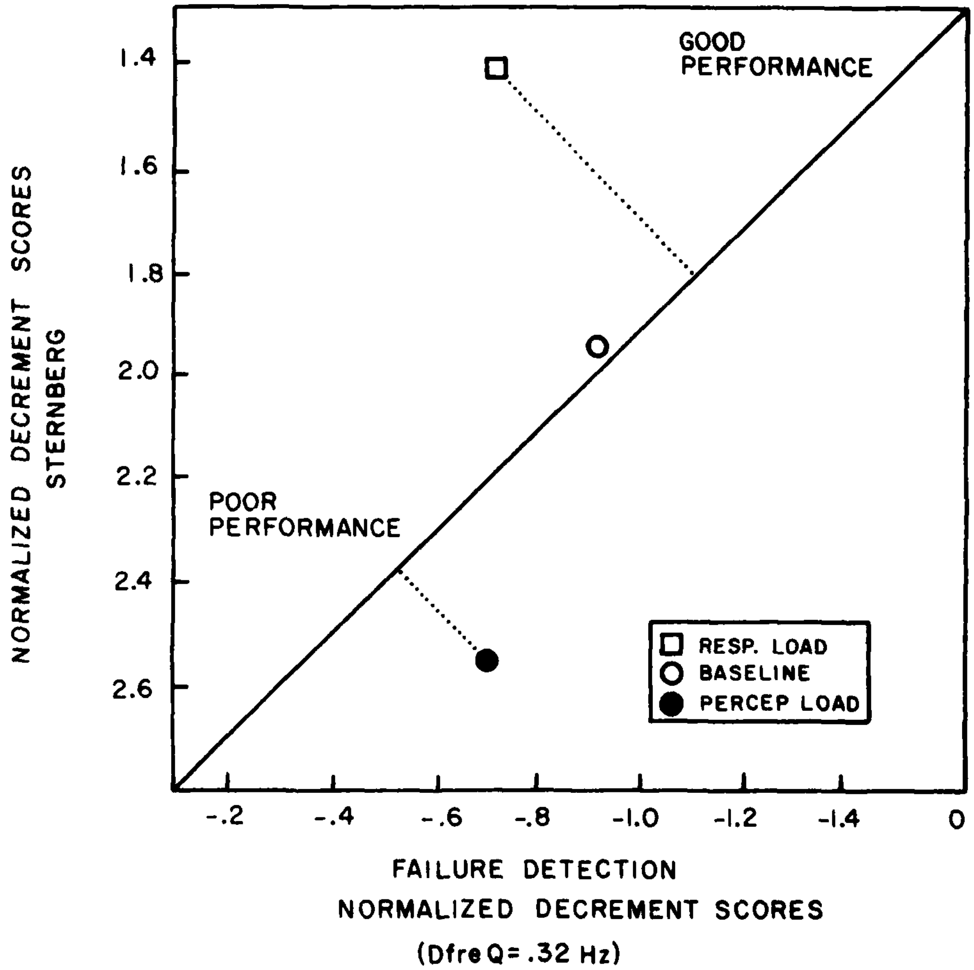

FIGURE 6. POC representation of dual task decrements (.32 Hz failure detection condition).

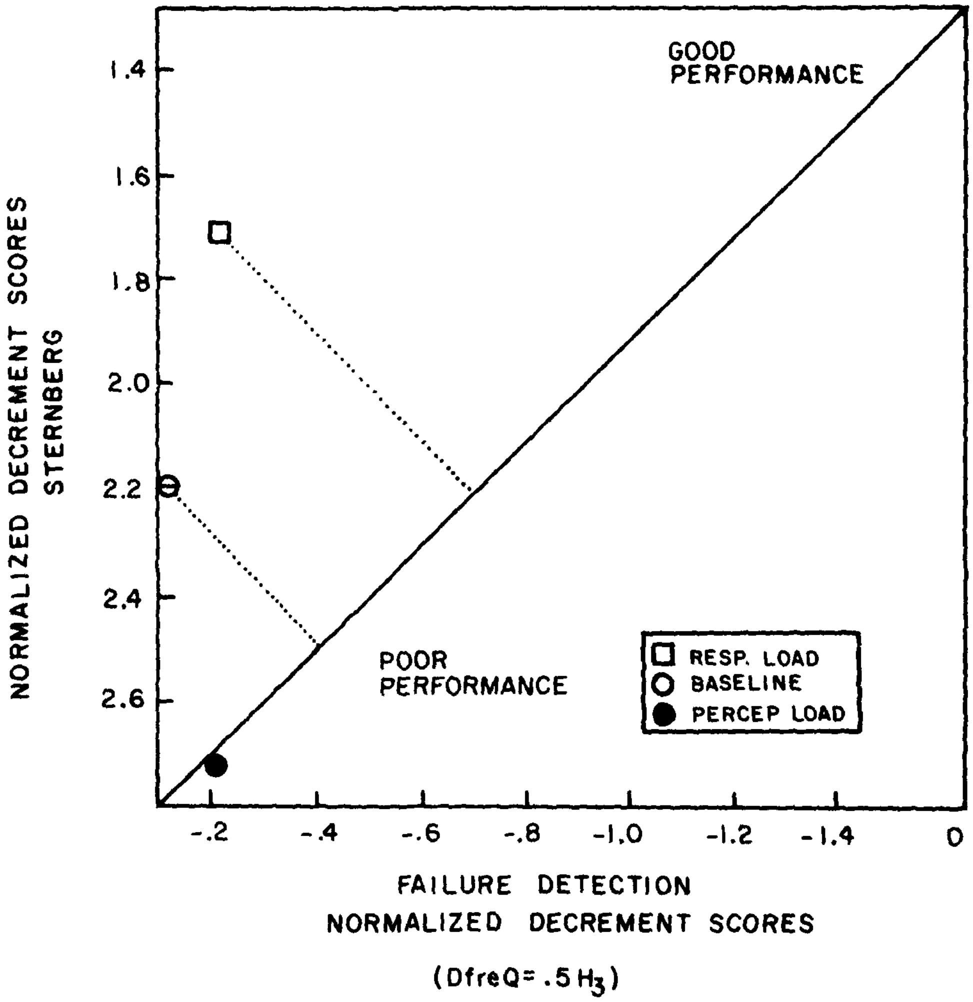

FIGURE 7. POC representation of dual task decrements (.50 Hz failure detection condition).

The results of the analysis of variance support the general impression conveyed by the respective POCs. A comparison of mean dual task failure detection hit latencies across Sternberg conditions reveals no significant variations, $F(2,14) = .234$, $p > .794$. The relatively higher perceptual load reaction times observed under dual task conditions were not necessarily accompanied by correspondingly lower failure detection latencies. The variation of dual task failure detection performance is not large enough to account for the larger decrements in reaction time performance.

It is also important to insure that the reaction time differences between the perceptual and response load conditions did not result from a speed/accuracy tradeoff. Table 3 contains a summary of the error data for both the failure detection and Sternberg tasks. The results indicate the Sternberg errors were significantly greater in the response load condition, $F(2,14) = 6.22$, $p < .05$. However, this error variation could be due to the increased opportunity for error in the double key response condition (recognition errors and double key response errors). More importantly, there was no interaction between Sternberg condition and single/dual task demands for reaction time errors. In other words, although the relative percentage of errors varied across Sternberg conditions, this variation was consistent for both single and dual task conditions. A speed/accuracy tradeoff explanation of the results could not be applied to the interpretations of the reaction time data which are concerned with performance variations as a function of Sternberg condition and single/dual task demands.

The effect of the various experimental conditions on the number of false alarms appeared to be generally insignificant, although under dual

Table 3

Error Data for the Failure Detection and Sternberg Tasks

Load	Baseline	Mask	Double Key
False Alarms			
Single Task			
.32 Hz	.063		
.50 Hz	.219		
Dual Task			
.32 Hz	.219	.375	.313
.50 Hz	.656	.219	.281
Percentage of Sternberg Errors			
Single Task			
	2.33	3.68	5.43
Dual Task			
.32 Hz	2.89	4.33	6.48
.50 Hz	3.20	3.11	6.50

The Baseline, Mask and Double Key columns are printed under the spanning heading "Condition".

task demands, there was a significant difference between the cutoff frequency manipulations for the baseline (no mask- single key) Sternberg condition, $F(2,14) = 6.86$, $p < .01$. However, comparisons with corresponding hit latencies does not indicate that this difference was in the direction of a speed/accuracy tradeoff. Of greatest importance is the fact that false alarm rate is essentially equivalent between the perceptual and response load conditions.

DISCUSSION

These experimental results provide at least some support for the main hypotheses advanced in the beginning of this report. First, the significant interaction between perceptual load and failure detection demands indicates some degree of processing resource overlap between these two tasks within the framework of the additive factors method. Second, the lack of a significant interaction between response load and failure detection demands provides evidence for the notion of a separation of the respective processing resource pools.

The failure detection task used in this study appears to be primarily perceptually loaded. This conclusion is consistent with previous studies (Wickens & Kessel, 1979, 1980), which investigated the resource demands of failure detection with a different secondary task. In addition, these results also support a stages of processing dimension for the structure specific resource model which is particularly applicable to workload investigations. The general Sternberg paradigm utilized in this study has shown promise as a technique for probing the multidimensionality of workload demands within the context of dual task methodology.

Comparisons of the dual task data obtained for the .32 Hz and .5 Hz

cutoff frequency manipulations must be accompanied by cautious interpertation of the experimental results. One aspect of the data which is not immediately interpretable within a resource competition model concerns the difference between single and dual task failure detection hit latency for the two cutoff frequency manipulations. As noted, the average single task failure detection hit latency for the .32 Hz manipulation was considerably higher than either its dual task value or the single or dual task latencies for the .5 Hz condition. This result suggests that dual task requirements actually increased failure detection performance in the .32 Hz condition. This might be explained in terms of relative arousal levels (Kaheneman, 1973). The slower dynamics of the .32 Hz system, producing a more gradually responding display, may have induced a lower level of arousal which contributed to the consistently higher single task hit latencies in this condition. However, under dual task conditions, the level of arousal increased in the .32 Hz condition to a level more comparable to the .5 Hz condition, and the performance in each condition was considerably more equivalent. Interpretations of the cutoff frequency manipulation as a manipulation of task difficulty are not clearly supported by the data even though, a priori, the increased velocity component in the .5 Hz condition *would seem to render this task subjectively more difficult.*

The average dual task Sternberg data did not vary significantly between the two cutoff frequency manipulations with the exception of the response load condition. The lower response load reaction time in the .32 Hz manipulation was primarily responsible for the significant 3-way interaction between the Sternberg conditions task load and the cutoff frequency manipulations ($F(2,14) = 4.20$, $p < .05$). An explanation for this shortening

of the dual task double response RT at the low cutoff relative to the high cutoff is not readily apparent either in terms of resource theory or in terms of an arousal explanation. It must therefore be attributed to statistical variability in the data.

Perhaps the most important contribution of this study has been to provide evidence for the utility of the general Sternberg paradigm in assessing the locus of processing resource demands for a particular primary task. The selective interaction with perceptual load was observed where it was predicted, as was the additivity or underadditivity with the response load manipulation. This procedure is especially appropriate for probing the multidimensional aspects of the generalized workload concept. In the present study the Sternberg stimuli were spatially defined dot patterns. The use of more traditional letter stimuli will be the subject of a future report (Wickens, Derrick, Beringer, & Micalizzi, 1980). It should be noted that the use of the visually defined Sternberg stimuli in the present investigation was potentially important. The results reviewed in the introduction suggested that deployment of auditory stimuli tended to provide underadditive relations with the memory set size variable. It is not clear if underadditivity is a general property of cross model stimuli. However, given the difficulty of interpretation of underadditive results, it seems that visual probes should be prescribed in the assessment of workload of a visual primary task.

Workload assessment continues to be an important activity in the human factors evaluation of complex system interactions. Although criticisms of the additive factors method (Pachella, 1974) and alternate conceptions of the structure of the reaction time interval (McClellan, 1978) may weaken the

theoretical basis for the Sternberg methodology, this method may still provide some degree of practical application in localizing the workload effects involved in man/machine systems.

REFERENCES

Briggs, G.E., Peters, G.L., & Fisher, R.P. On the locus of the divided-attention effects. Perception and Psychophysics, 1972, 11, 315-320.

Briggs, G.E., & Swanson, J.M. Encoding, decoding, & central functions in human information processing. Journal of Experimental Psychology, 1970, 86, 296-308.

Broadbent, D.E. A mechanical model for human attention and immediate memory. Psychological Review, 1957, 63(3), 205-215.

Broadbent, D.E., & Gregory, M. On the interaction of S-R compatibility with other variables affecting reaction time. British Journal of Psychology, 1965, 56, 61-67.

Brown, I.D. Dual tasks methods of assessing mental workload. Ergonomics, 1978, 21, 221-224.

Bryden, M.P. Measuring handedness with questionnaires. Neuropsychologia, 1977, 15, 617-624.

Clement, W.F., McRuer, D.T., & Klein, R. Systematic manual control display design. Guidance and Control Displays Conference, Agard Conference Proceedings #96, 1971.

Crawford, B.M., Pearson, W.H., & Hoffman, M.S. Multipurpose switching and flight control workload. Proceedings of the Sixth Symposium on Psychology in the Department of Defense, 1978, 219-221.

Curry, R.E. Mental load in monitoring tasks. In N. Moray (Ed.), Mental Workload: Its Theory and Measurement. New York: Plenum Press, 1979.

Curry, R.E., & Eprath, A.R. Monitoring and control of unreliable systems. In T.B. Sheridan & G. Johannsen (Eds.), Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976.

Curry, R.E., & Gai, E.G. Detection of random process failures by human monitors. In T.B. Sheridan & G. Johannsen (Eds.), _Monitoring Behavior and Supervisory Control_. New York: Plenum Press, 1976.

Damos, D., & Wickens, C.D. Dual task performance and the Hick-Hyman law of choice reaction time. _Journal of Motor Behavior_, 1977, _9_, 209-215.

Egeth, H. Attention and pre-attention. In G.H. Bower (Ed.), _The Psychology of Learning and Motivation_ (Vol. _11_). New York: Academic Press, 1977.

Eprath, A.R., & Curry, R.E. Detection by pilots of system failures during instrument landings. _IEEE Transactions on Systems, Man, and Cybernetics_, 1977, _SMC-11_, 72-80.

Eriksen, C.W., Pollack, M.D., & Montague, W. Implicit speech: Mechanisms in perceptual encoding? _Journal of Experimental Psychology_, 1970, _84_, 502-507.

Gai, E.G., & Curry, R.E. Failure detection by pilots during automatic landings: Models and experiments. _Proceedings of the 11th Annual Conference on Manual Control_, 1975, 78-93.

Griffeth, D., & Johnston, W.A. Stage 2 processing and the divided attention effect. _Memory & Cognition_, 1977, _5_, 597-601.

Isreal, J., Wickens, C.D., Chesney, G.L., & Donchin, E. The event-related brain potential as an index of display monitoring workload. _Human Factors_, 1980, _22_(2), 211-224.

Jagacinski, R.J., & Miller, R.A. Describing the human operator's internal model of a dynamic system. _Human Factors_, 1978, _20_, 425-433.

Jex, H.R. Two applications of the critical instability task to secondary workload research. _IEEE Transactions on Human Factors in Electronics_, 1967, _HFE-8_, 279-282.

Johannsen, G., Pfendler, C., & Stein, W. Human performance and workload in simulated landing-approaches with auto-pilot failures. In T.B. Sheridan & G. Johannsen (Eds.), _Monitoring Behavior and Supervisory Control_. New York: Plenum Press, 1976.

Kahneman, D. Attention and effort. Englewood Cliffs, New Jersey: Prentice Hall, 1973.

Kantowitz, B.H., & Knight, J.L. Testing tapping and time-sharing II: Use of the auditory secondary task. Acta Psychologica, 1976, 40, 343-362.

Keele, S.W. Compatibility and time-sharing in serial reaction time. Journal of Experimental Psychology, 1967, 75, 529-539.

Keele, S.W. Attention and human performance. Pacific Palisades, CA: Goodyear Publishing Co., Inc., 1973.

Kerr, B. Processing demands during mental operations. Memory and Cognition, 1973, 1, 401-412.

Kleinman, D.L., & Curry, R.E. Some new control theoretic models for human operator display. IEEE Transactions on Systems, Man, and Cybernetics, 1977, SMC-7, 778-784.

Kvalseth, T.O. A decision-theoretic model of the sampling behavior of the human process monitor: Experimental evaluation. Human Factors, 1979, 21, 671-686.

Levison, W.H., & Tanner, R.B. A control theory model for human decision making (NAS2-5884). Bolt, Beranek, & Newman, Inc., June, 1971.

Logan, G.D. Attention in character-classification tasks: Evidence for the automaticity of component stages. Journal of Experimental Psychology, 1978, 107, 32-63.

Logan, G.D. On the use of a concurrent memory load to measure attention and automaticity. Journal of Experimental Psychology: Human Perception & Performance, 1979, 5, 189-207.

McClellan, J.L. On the time relations of mental processes: A framework for analyzing processes in cascade. Chip Report 77, Center for Human Information Processing, University of California, San Diego, 1978.

Moray, N. Where is capacity limited? A survey and a model. Acta Psychologica, 1967, 27, 84-92.

Moray, N. Mental workload: Its theory and measurement. New York: Plenum Press, 1979.

Norman, D. Toward a theory of memory and attention. Psychological Review, 1968, 75, 522-536.

Ogden, G.D., Levine, J.M., & Eisner, E.J. Measurement of workload by secondary tasks. Human Factors, 1979, 21(5), 529-548.

Pachella, R.G. The interpretationof reaction time in information processing research. In B. Kantowitz (Ed.), Human Information Processing: Tutorials in Performance and Cognition. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1974.

Posner, M.I., & Boies, S.J. Components of attention. Psychological Review, 1971, 78, 391-408.

Rasmussen, J. On the communication between operators and instrumentation in automatic process plants. Danish Atomic Energy Commission, RISO-M-686, 1968.

Rouse, W.B. A model of the human in a cognitive prediction task. IEEE Transactions on Systems, Man, and Cybernetics, 1973, SMC-3, 473-477.

Rouse, W.B. A model of the human as a suboptimal smoother. IEEE Transactions on Systems, Man, and Cybernetics, 1976, SMC-6, 337-343.

Schiflett, S.G. Evaluation of a pilot workload assessment device to test alternate display formats & control handling qualities. Naval Air Test Center Final Report SY-33-R-80, July, 1980.

Senders, J.W. The human operator as a monitor and controller of multidegree of freedom systems. IEEE Transactions on Human Factors in Electronics, 1974, HFE-5, 2-5.

Sheridan, T.B. On how often the supervisor should sample. IEEE Transactions on Systems, Science, and Cybernetics, 1970, SSC-6, 140-145.

Sheridan, T.B. Toward a general model of supervisory control. In T.B. Sheridan & G. Johannsen (Eds.), Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976.

Shulman, H.G., & Greenberg, S.M. Perceptual deficit due to division of attention between memory and perception. Journal of Experimental Psychology, 1971, 88, 171-176.

Smallwood, R.D. Internal models and the human instrument monitor. IEEE Transactions on Human Factors in Electronics, 1967, HFE-8, 181-187.

Spicuzza, R., Pincus, A., & O'Donnell, R.D. Development of performance assessment methodology for the digital avionics information system. Dayton, Ohio: Systems Research Laboratories, Inc., August, 1974.

Sternberg, S. High speed scanning in human memory. Science, 1966, 153, 652-654.

Sternberg, S. Two operations in character recognition: Some evidence from reaction time measurements. Perception and Psychophysics, 1967, 2, 45-53.

Sternberg, S. The discovery of processing stages: Extensions of Donder's method. Acta Psychologica, 1969, 30, 276-315. (A).

Sternberg, S. Memory scanning: Mental processes revealed by reaction time experiments. American Scientist, 1969, 57, 421-457. (B).

Treisman, A.M. Monitoring and storage of irrelevant messages in selective attention. Journal of Verbal Learning and Verbal Behavior, 1964, 3, 449-459.

Tversky, A., & Kahneman, D. Judgment under uncertainty: Heuristics & biases. Science, 1974, 185, 1124-1131.

Veldhyzen, W., & Stassen, H.G. The internal model concept: An application to modeling human control of large ships. Human Factors, 1977, 19(4), 367-380.

Veldhyzen, W., & Stassen, H.G. The internal model: What does it mean in human control. In T.B. Sheridan & G. Johannsen (Eds.), Monitoring Behavior and Supervisory Control. New York: Plenum Press, 1976.

Wickens, C.D. The effects of divided attention on information processing in tracking. Journal of Experimental Psychology: Human Perception and Performance, 1976, 2, 1-13.

Wickens, C.D. Measures of workload, stress, and secondary tasks. In N. Moray (Ed.), Mental Workload: Its Theory and Measurement. New York: Plenum Press, 1979.

Wickens, C.D. The structure of attentional resources. In R. Nickerson & R. Pew (Eds.), Attention and Performance VIII. Englewood Cliffs, New Jersey: Lawrence Erlbaum Associates, 1980.

Wickens, C.D., Derrick, W.L., Beringer, D.B., & Micalizzi, J. The structure of processing resources: Implications for task configuration and workload. Proceedings of the 24th Annual Meeting of the Human Factors Society, Los Angeles, California, 1980.

Wickens, C.D., & Kessel, C.J. The effects of participatory mode and task workload on the detection of dynamic system failures. IEEE Transactions on Systems, Man, and Cybernetics, 1979, SMC-13, 24-31. (A)

Wickens, C.D., & Kessel, C.J. The processing resource demands of failure detection in dynamic systems (Tech. Rep. EPL-79-1/AFOSR-79-1). Champaign-Urbana, Illinois: University of Illinois, Engineering-Psychology Laboratory, January, 1979. (B)

Wickens, C.D., & Micalizzi, J. The central processing resource demands of failure detection. Unpublished manuscript, University of Illinois, 1980.

Wickens, C.D., Mountford, S.J., & Schreiner, W. Task dependent differences and individual differences in dual task performance (Time-sharing efficiency: Evidence for multiple resources, task hemispheric integrity, and against a general ability. Human Factors,1981, 23, (in press)).

Wickens, C.D., & Sandry, D.L. An investigation of the dual-task performance relationship to hemispheric specialization (Tech. Rep. EPL-80-1/ONR-80-1). Champaign-Urbana, Illinois: University of Illinois, Engineering-Psychology Laboratory, June, 1980.

Wierwille, W.W., & Williges, R.C. Survey and analysis of operator work-load assessment techniques. Blacksburg, Virginia: Systemetrics, Inc., Report No. S-78-101. September, 1978.

Young, L.R. On adpative manual control. IEEE Transactions on Man Machine Systems, 1969, MMS-10, 292-331.

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